NOMADS: UNCOVERING THE ORIGIN OF REMNANT PLANETS IN THE HOT NEPTUNIAN DESERT

1. THE NEPTUNIAN DESERT

- The exoplanet population does not have a uniform distribution in period, radius, and mass.
  - There is a lack of Neptunes (intermediate sized planets approx. $0.02 < M_P < 0.8\ M_J$ and 2 - 4 R_E) at short periods (≲ 3 d)
  - You can see this as a wedge-shaped region in both period-radius (Fig 1, shaded area) and period-mass planes, and it is called the "Neptunian Desert"
  - Mazeh+ (2016) showed that the desert has 2 boundaries (Fig 1, solid lines)
  - The desert cannot be an observational bias: short period planets of intermediate size are easy to detect and characterise!
- The lower boundary of the desert could be set by photoevaporation of planets above the boundary, stripping their envelopes and reducing their radii/mass.
  - Owen & Lai (2018) defined a boundary based on this concept for different core masses (e.g., Fig 1, dashed line, for a 13.75 M_E core).
- The position of the upper boundary seems to be too high for the desert to be explained by photoevaporation alone; instead, close-in Jupiters might have undergone high-eccentricity migration to reach their present-day orbits.
  - The boundary might be understood as a "tidal disruption barrier", where planets below and left of the boundary migrating inwards can no longer successfully circularise and stabilise.
  - This was deduced by Owen & Lai (2018) and supported by Vissapragada+ (2022).

2. WHAT IS "NOMADS"?

- The desert has been shown to not be quite so dry, as a handful of "nomad" planets inside its boundaries have now been found, e.g.: TOI-849b (Armstrong+ 2020), NGTS-4b (West+ 2019), LTT-9779b (Jenkins+ 2020), and TOI-2196b (Persson+ 2022).
- The all-sky nature of TESS has significantly increased the population of nomads.

Our "NOMADS" large programme on the HARPS spectrograph aims to study the nature and origin of the Neptunian Desert by precisely characterising ~30 nomad planets, substantially increasing the current sample of planets with precisely measured masses (better than 20% errors) and radii in the desert, particularly in the 'deep desert' far from the boundaries.

- Need masses to constrain densities and thus infer composition.
- The resulting sample of characterised planets will provide the basis for theoretical studies of the processes that place planets inside the desert, allowing us to push the boundaries of planet formation models and test them against nomad benchmarks.

Period = 3.18 d
Radius = 3.19 $R_⊕$
Mass = 16.1 $M_⊕$
Density = 2.74 g cm^{-3}
Eccentricity = 0.132

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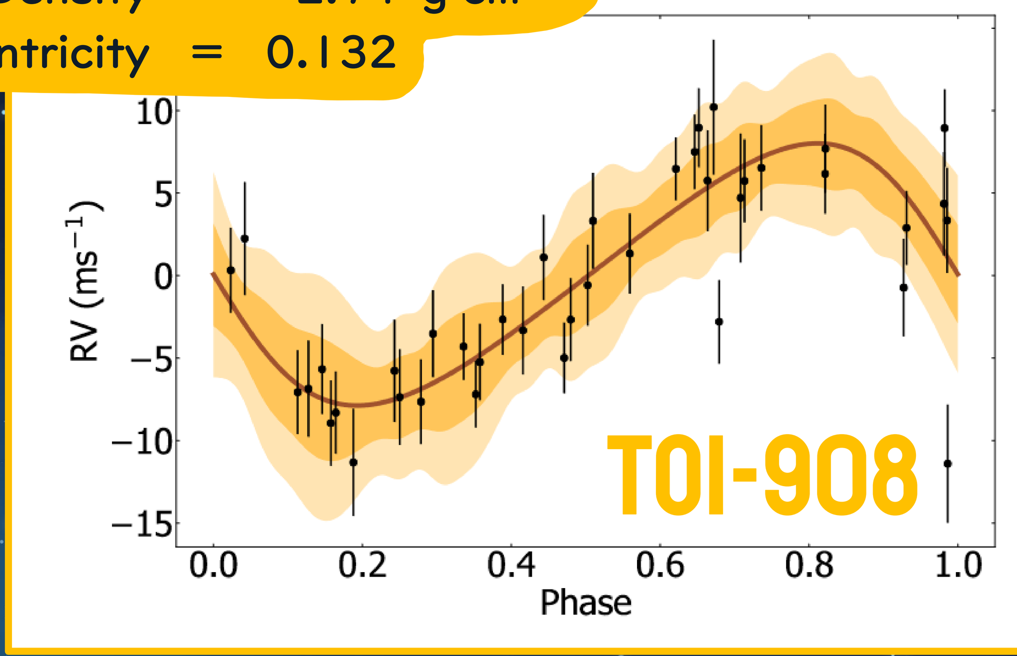
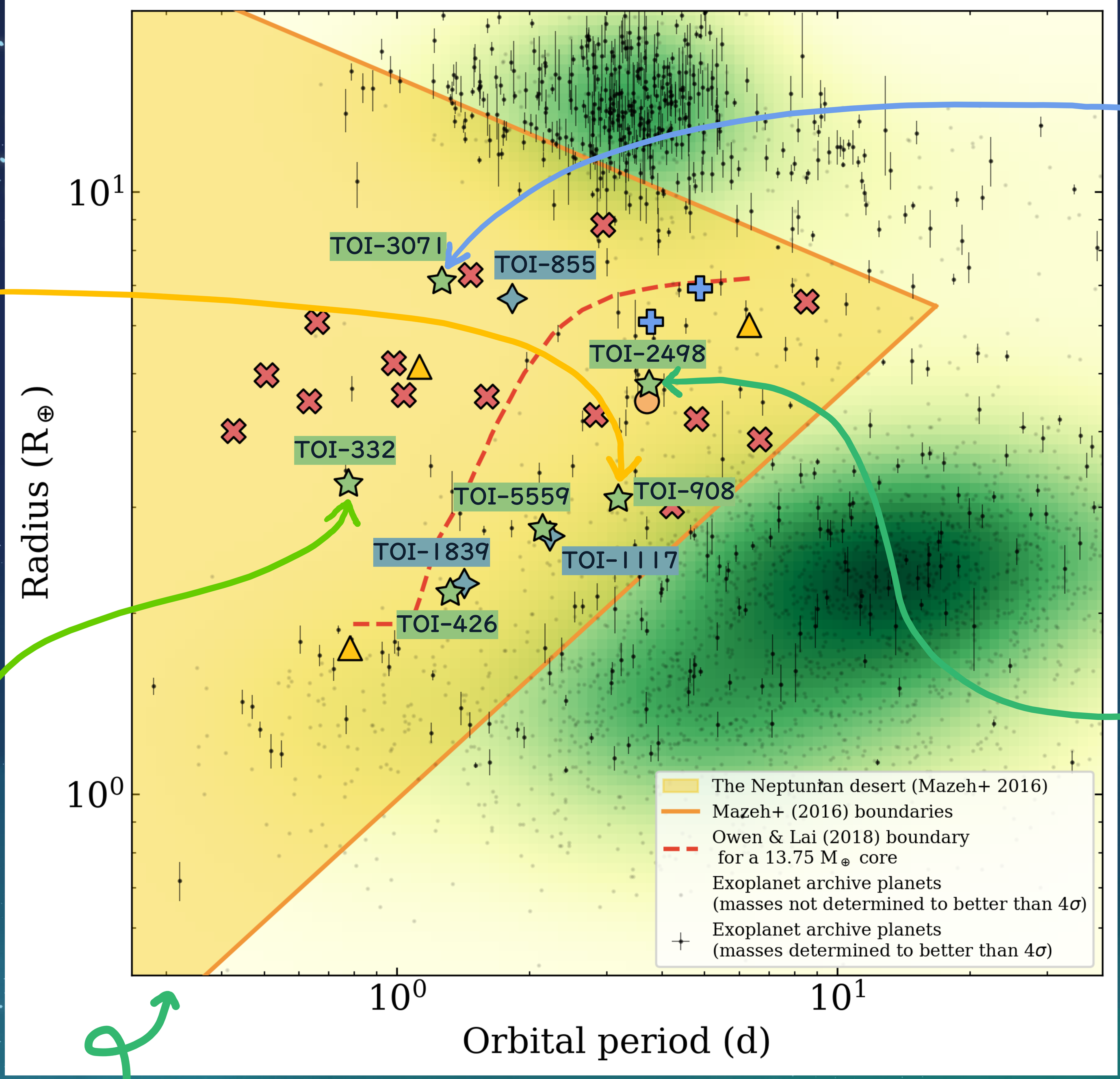


"a planet at the edge of the Neptune desert transiting a G-type star"

Fig. 1: a view of the Neptunian desert, with the Nomads sample overplotted



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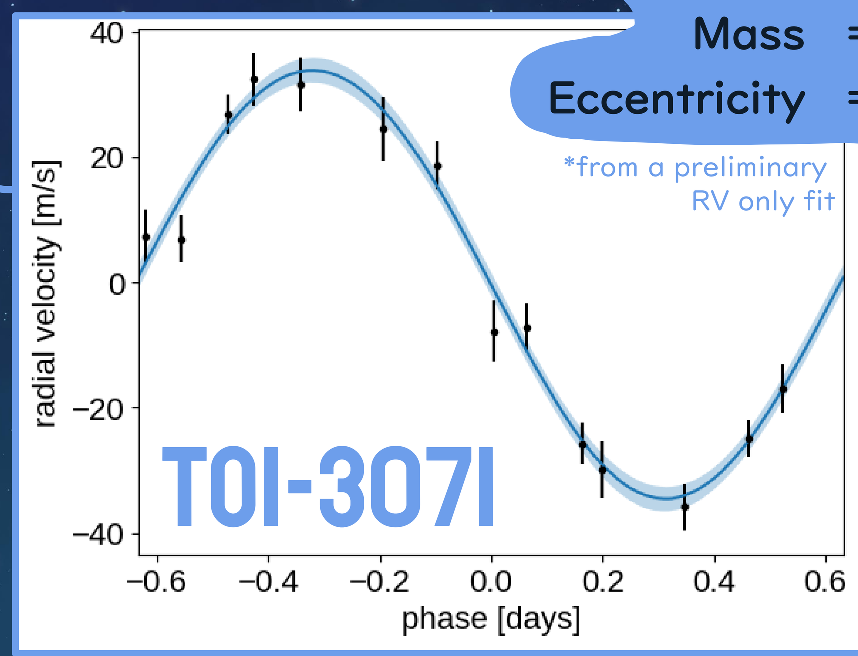
Period = 1.27 d
Radius = 7.14 $R_⊕$
Mass = 68.8 $M_⊕$
Eccentricity = 0.039



Period = 0.78 d
Radius = 3.21 $R_⊕$
Mass = 57.0 $M_⊕$
Density = 9.5 g cm^{-3}

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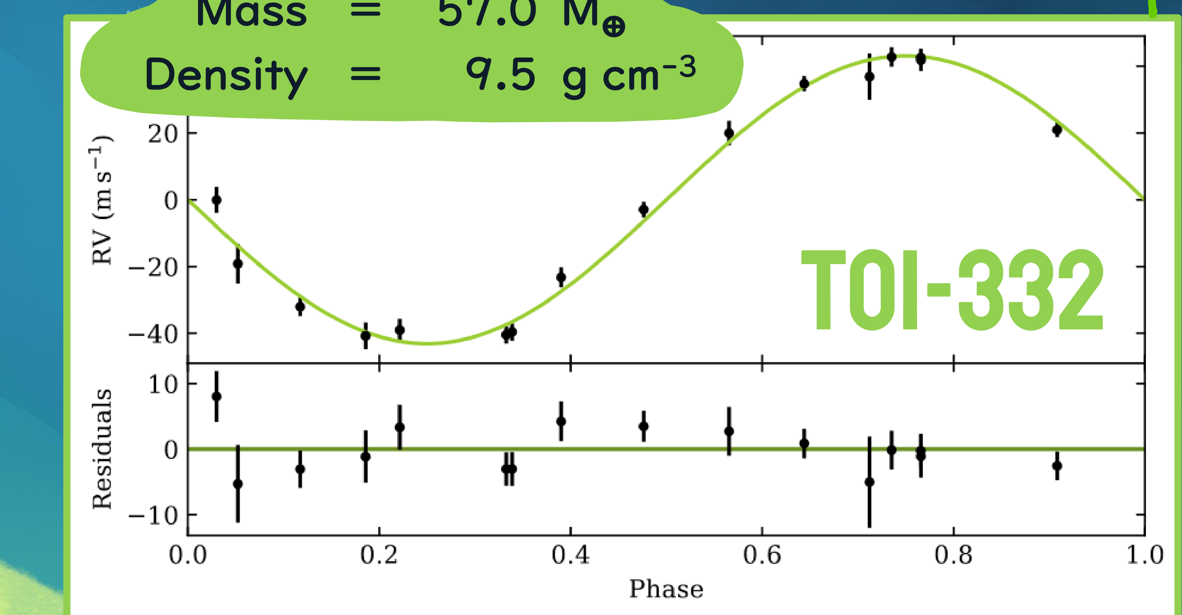

"the densest known Neptune found deep within the Neptunian desert"

See the poster for TOI-332 next to this one!

"a hot bloated super-Neptune within the Neptune desert"

Period = 3.74 d
Radius = 6.27 $R_⊕$
Mass = 34.02 $M_⊕$
Density = 0.758 g cm^{-3}
Eccentricity = 0.10

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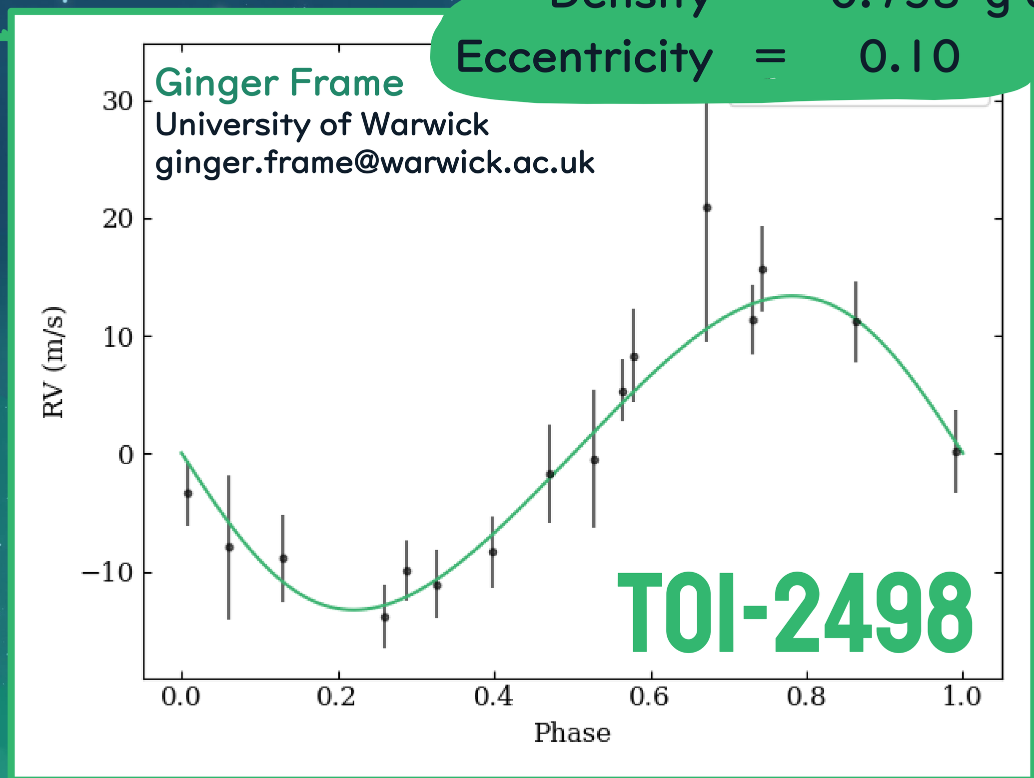


3. NOMADS SAMPLE

- We want to investigate the planets in the desert in a homogeneous and statistically significant way.
- Target list is drawn from TESS Objects of Interest (TOIs) within the desert boundaries defined by Mazeh+ (2016), and cuts are made to produce the sample:
  - Only FGK stars;
  - Within HARPS constraints: position on sky, brightness, stellar activity;
  - Well-vetted candidates (photometry and recon spectroscopy);
  - Rank by brightness and distance from desert boundaries.
- Results in 62 planets, 35 of which are already published/in-prep
  - Nomads is thus following up 27 desert planets (Fig. 1)

4. PLANETS OBSERVED SO FAR

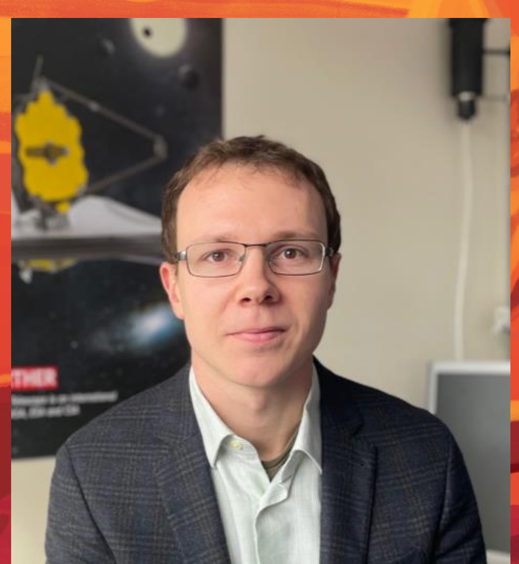
- ✖ 14 Nulls - expected signal not existent, strong stellar activity, but can get mass upper limits
- ● 1 not started - yet to take data (but will be soon)
- ▲ 3 WIPs - data collection ongoing
- ✚ 2 to contribute - we have some data, but other groups will be publishing the planets
- ◆ 3 tentatively publishable - the stellar activity needs fitting with a GP to pin down planet signal properly
- ☆ 6 publishable - analysis ongoing, papers in progress, see the 4 planets shown above as examples!

5. FUTURE WORK

- We are building towards a population level statistical understanding of planets in and around the desert, with the NOMADS project as precursor work.
- Through combining these results with automatic detection and validation pipelines, along with further uniform follow-up observations, we aim to uncover an unbiased picture of planetary densities in the desert.

SUMMARY

- We're actively following up TESS Objects of Interest in the Neptunian desert (a region of period-radius / period-mass space where planets are uncommon) with the HARPS spectrograph to determine their masses - this is the NOMADS programme.
- We are following up a sample of 27 desert planets, and, so far, have good mass determinations for 6 planets, and have followed up many others.
- If you think you've got targets that overlap ours, please feel free to contact us for collaboration.
- Keep an eye out for upcoming publications - TOI-332, TOI-908, TOI-3071, TOI-2498… and more to come!



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Background illustration by Ares